BSM HIGGS PHYSICS AT THE TEVATRON

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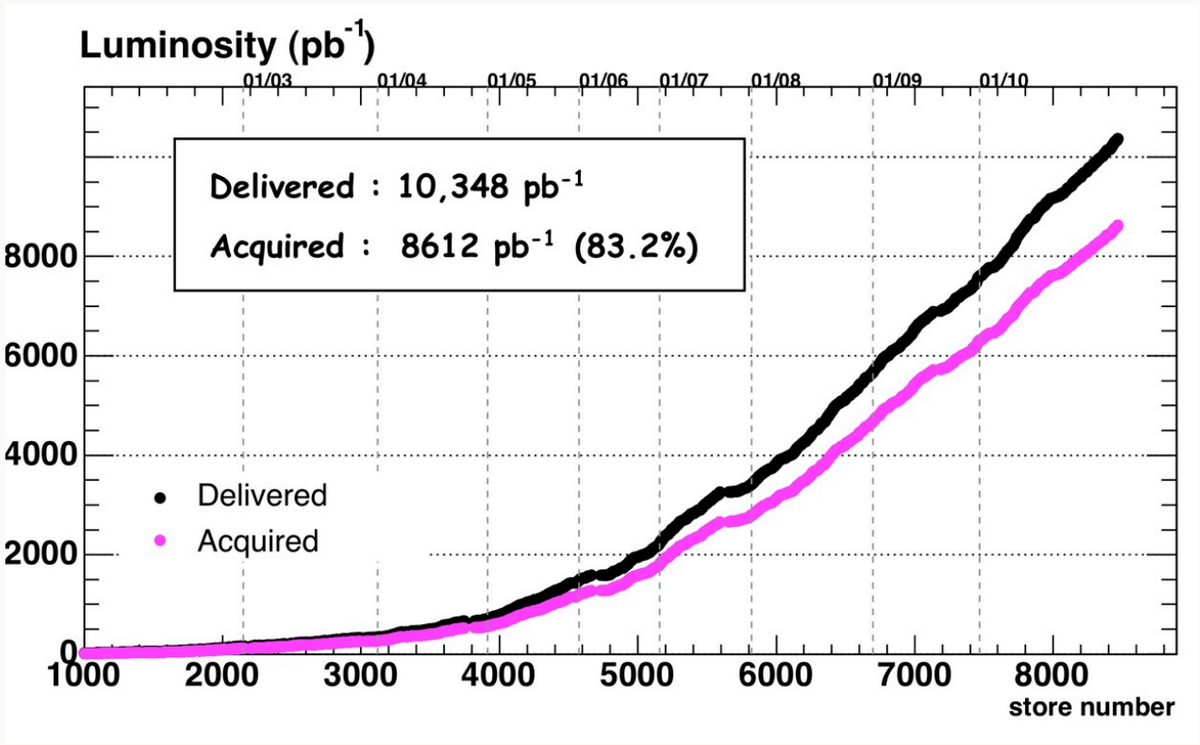
OUTLINE

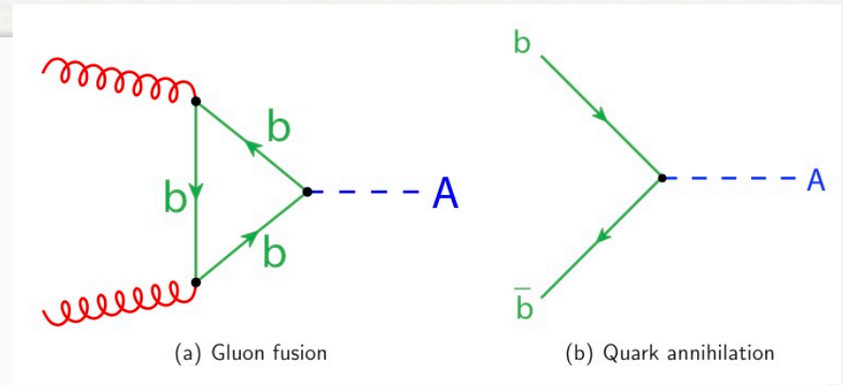
- Introduction
- MSSM Neutral Higgs
- MSSM Charged Higgs
- NMSSM Higgs
- Fermiophobic Higgs

TEVATRON

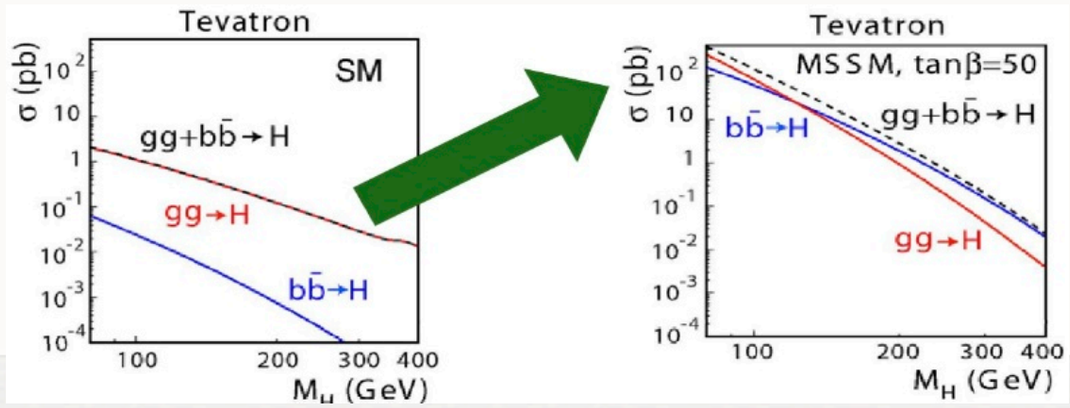
- Running well, has delivered 10 fb^{-1} with more than 8 fb^{-1} recorded to tape
- Results shown use up to 5.2 fb^{-1}



MSSM HIGGS

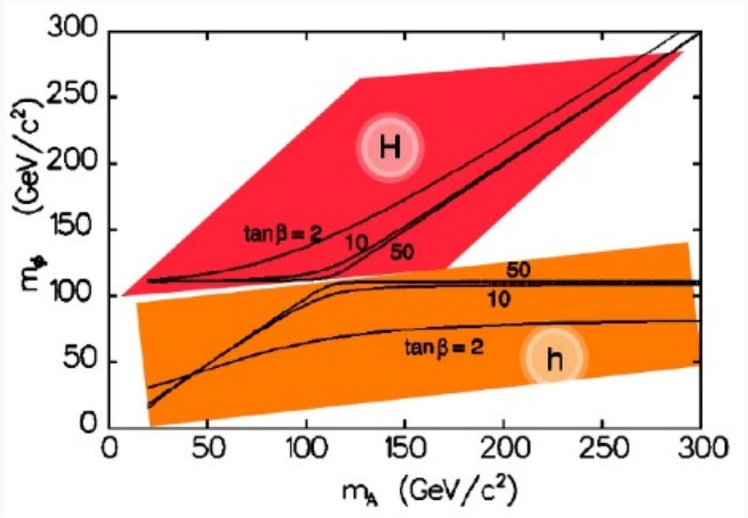


- MSSM Higgs
  - Five Higgs bosons expected, h, H, A and $H^{\pm}$
    - h,H are neutral scalars, A neutral pseudoscalar
    - $H^{\pm}$ charged higgs bosons
  - Described at tree-level by two parameters
    - m_A and tan β = the ratio of the vacuum expectation values of up-type and down-type scalar fields



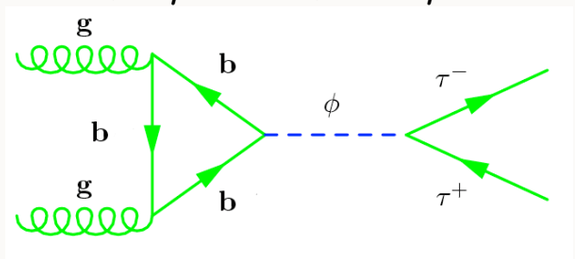
MSSM NEUTRAL HIGGS

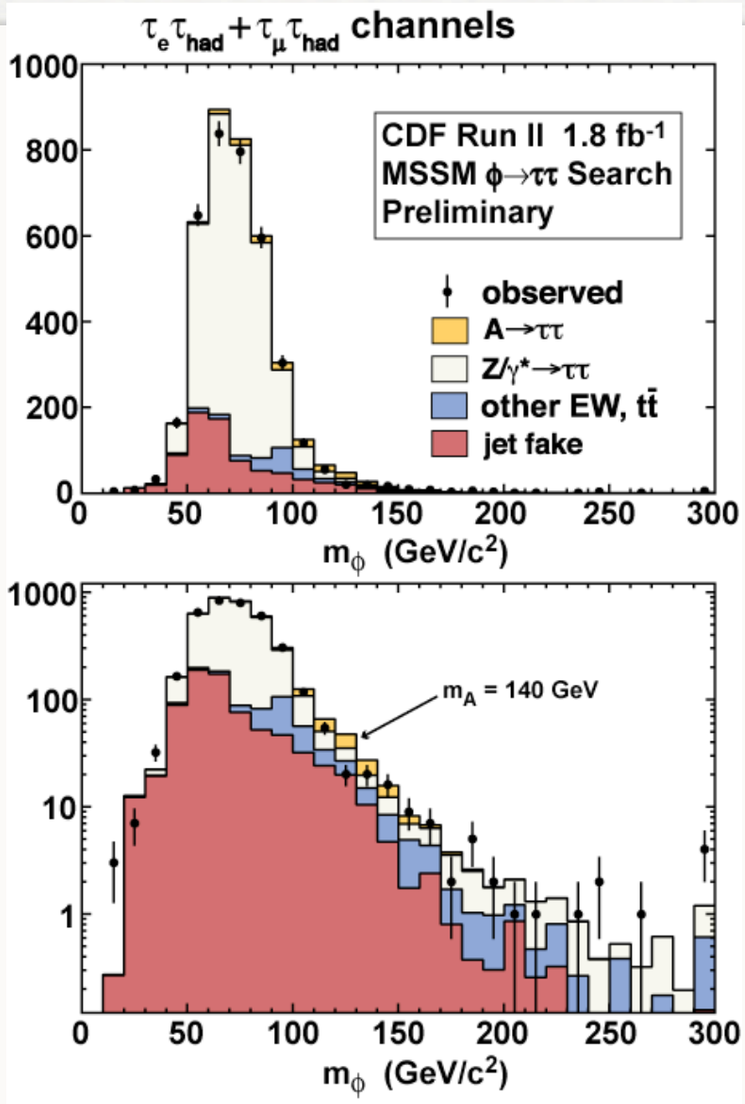
- MSSM Neutral Higgs
  - Neutral Higgs
    - Large tan β leads to mass degeneracy between h/A or H/A and enhanced coupling to down-type fermions
  - Decays Φ -> $b\bar{b}$ (90%) and Φ -> ττ (10%)
  - Three channels of interest
    - Φ -> ττ: cleaner signature
    - Φb->ττb: very clean signature, but low cross section
    - Φb -> bbb: high cross section

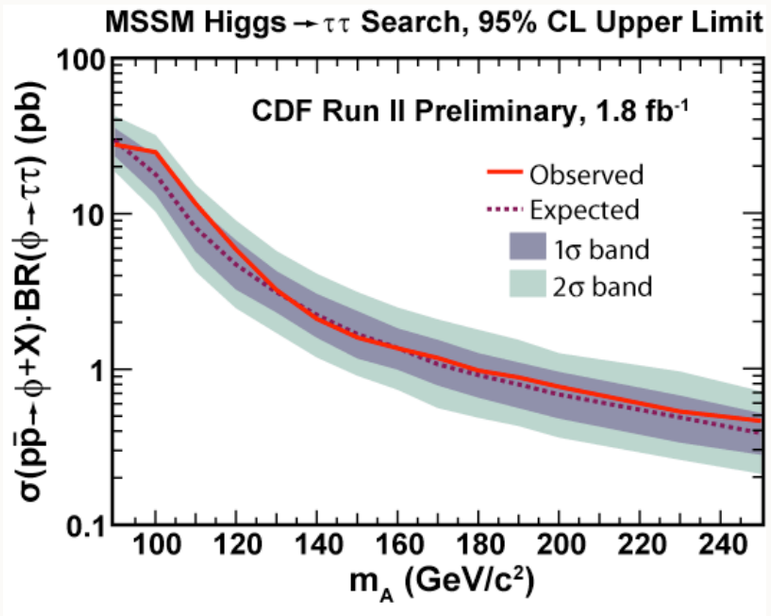


MSSM HIGGS->TAUTAU

- Three channels $\tau_e\tau_{had}$, $\tau_\mu\tau_{had}$, $\tau_e\tau_\mu$
- Backgrounds
  - Z, Drell-Yan, diboson, W: MC
  - QCD: fakes and sidebands from data



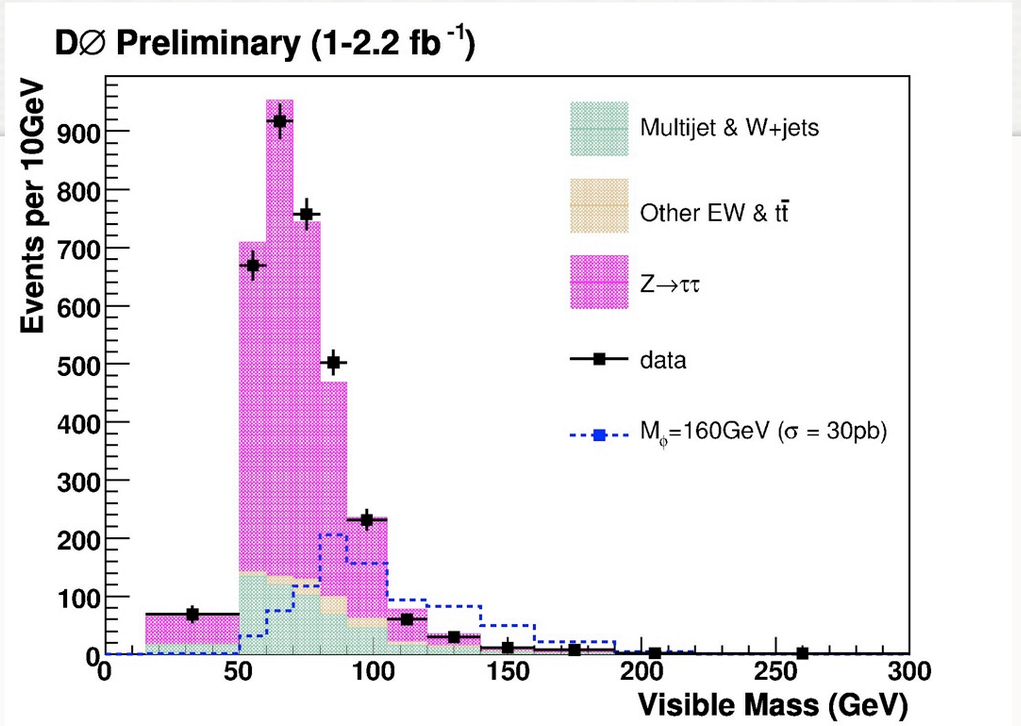


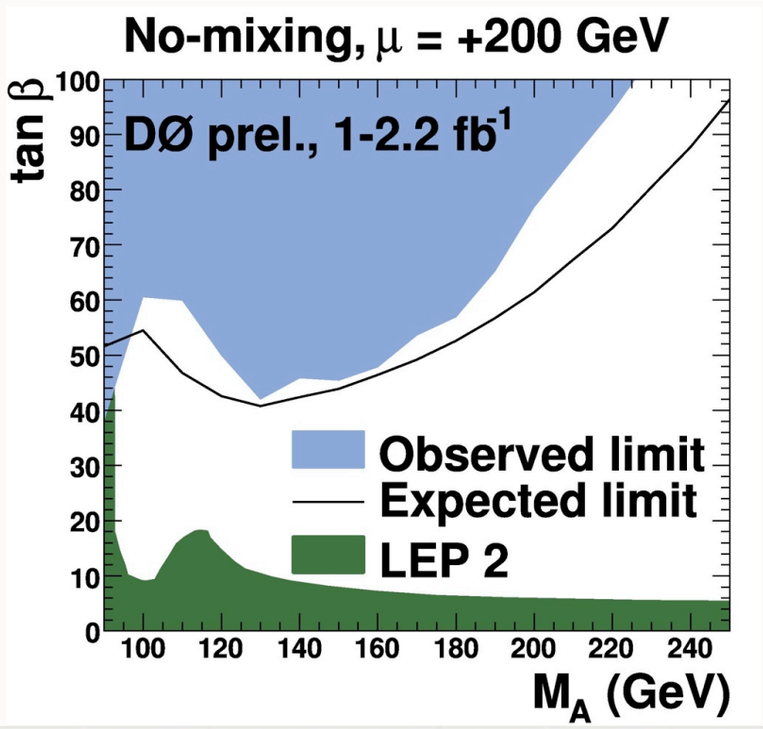


- Discriminate using visible mass $m_{vis} = \sqrt{(p_l + p_\tau + \not{E}_T)^2}$

$$m_{vis} = \sqrt{(p_e + p_\mu + \not{E}_T)^2}$$

MSSM HIGGS->TAUTAU





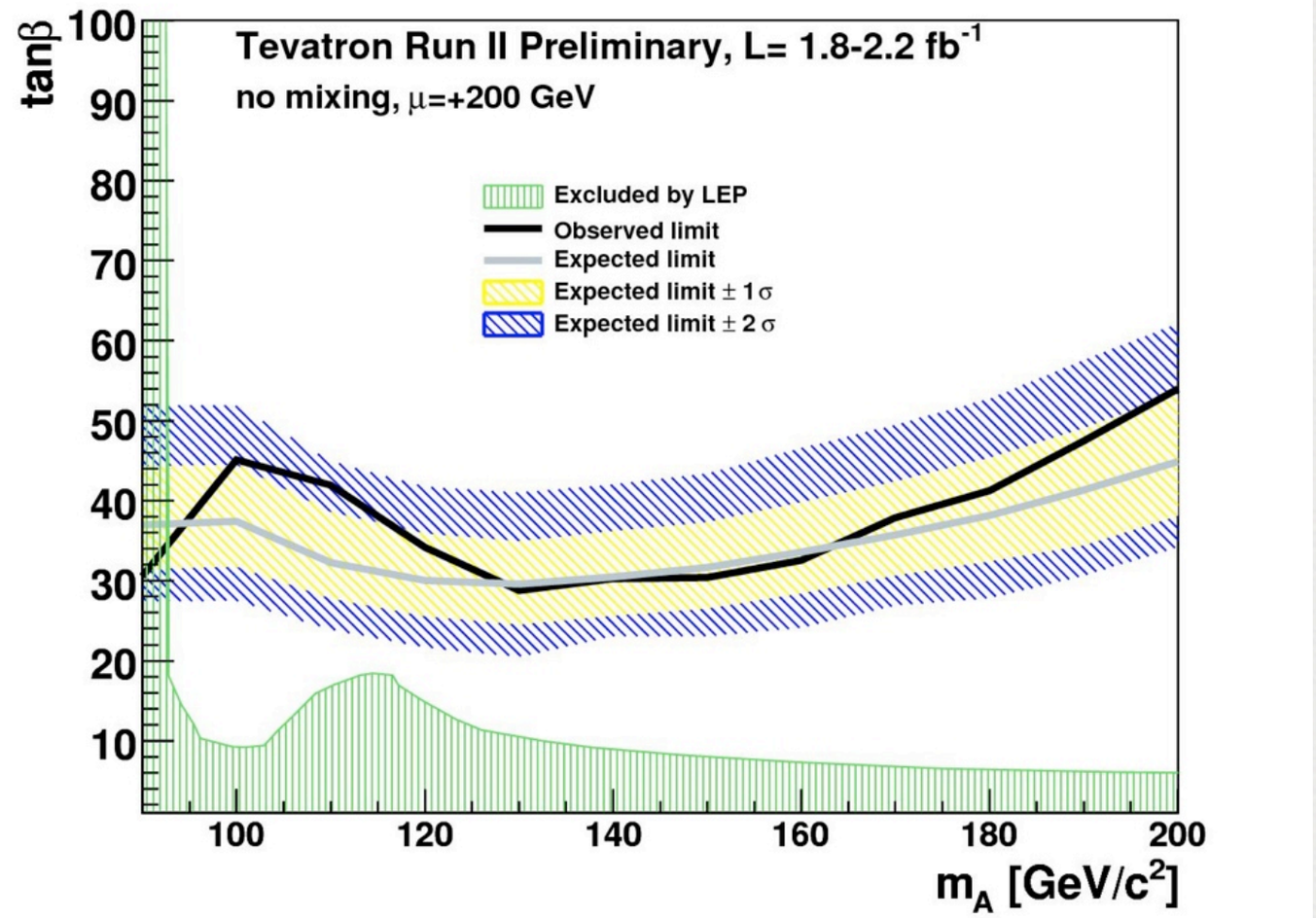
- Combines two different ditau analysis
  - Run IIa: hadronic tau + electron/muon, electron +muon channel analysis with 1.0 fb
  - Run IIb: hadronic tau+muon, electron +muon channel analysis with 1.2 fb
- Uses visible mass as discriminator

TEVATRON DITAU COMBINATION

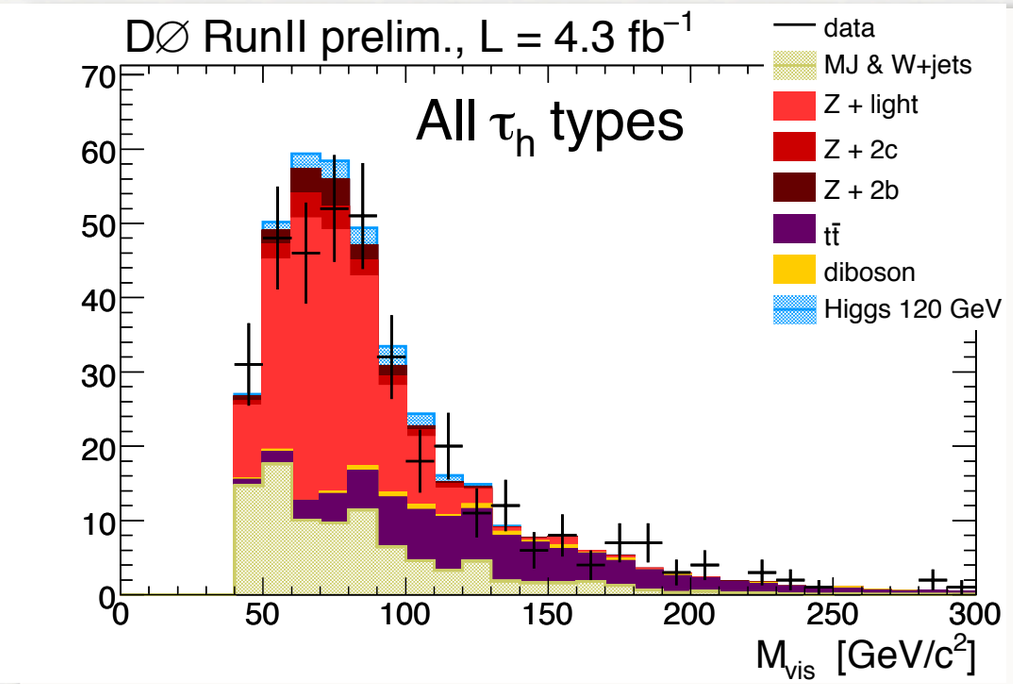
- Combines all CDF and DØ di-tau final state searches

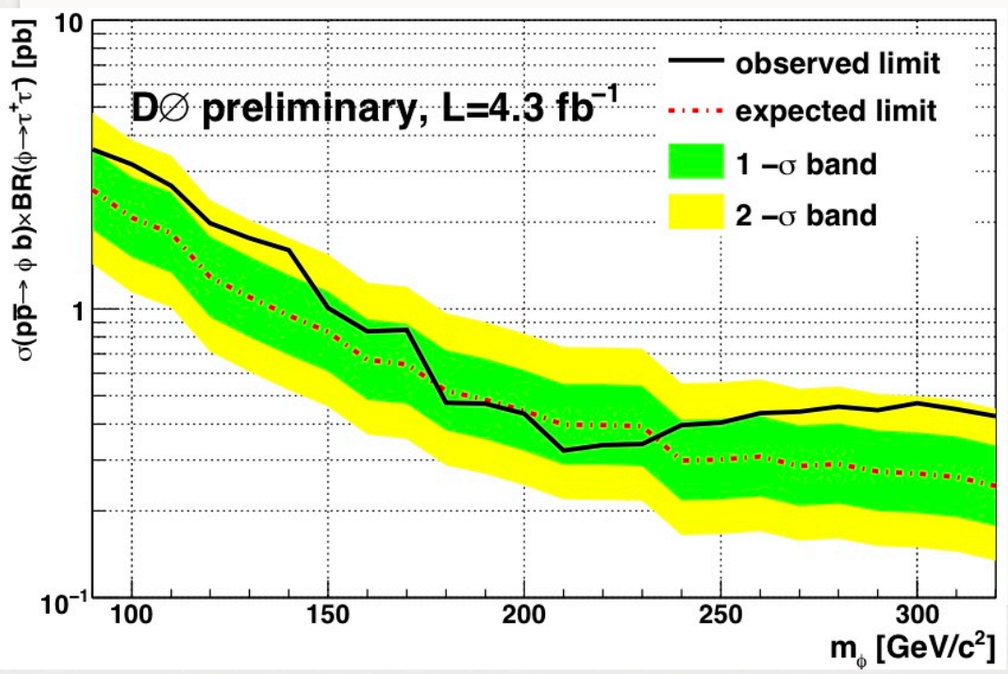
- Same combination methodology as employed for SM combination

	CDF	D0
$\tau_e+\tau_h$	1.8 fb^{-1}	1.0 fb^{-1}
$\tau_\mu+\tau_h$	1.8 fb^{-1}	1.0 + 1.2
$\tau_e+\tau_\mu$	1.8 fb^{-1}	1.0 fb^{-1}



MSSM HIGGS->TAUTAUB

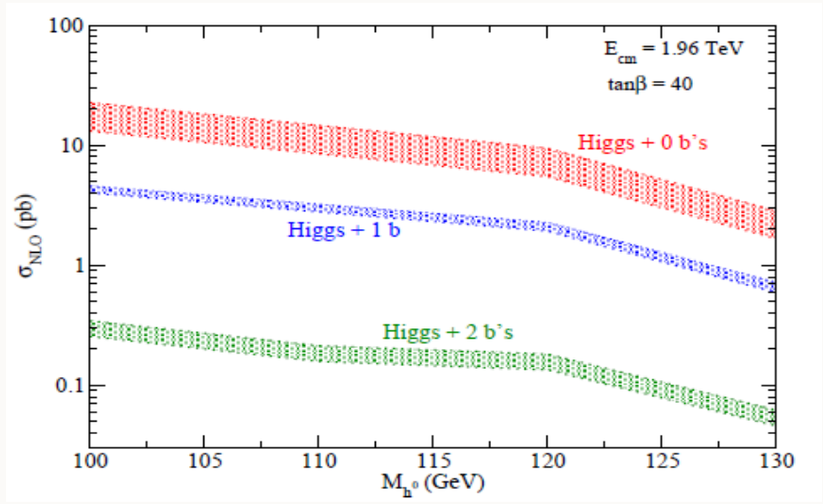


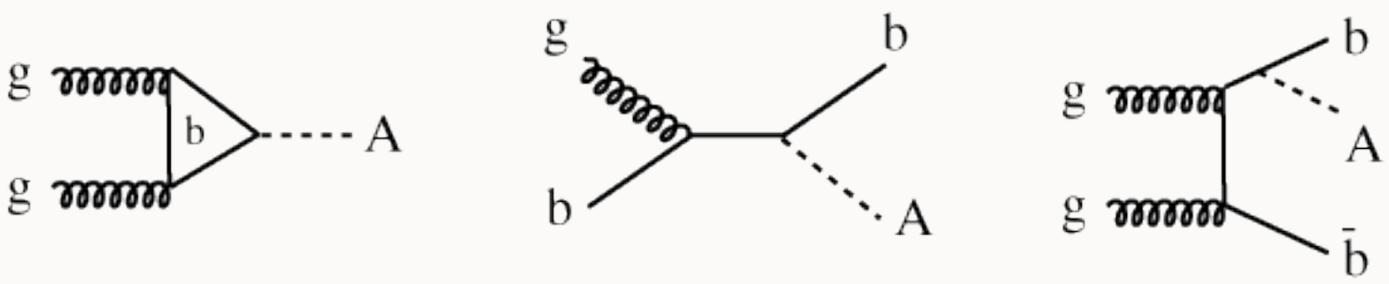


- Event selection for hadronic tau+muon + b-jet, using neural net tau ID and b-tagger
- Primary backgrounds are Z+jets, multijet and ttbar and are modelled from MC
- Uses neural net discriminator

MSSM NEUTRAL HIGGS

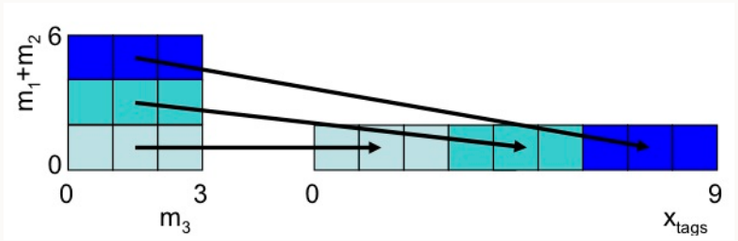
- MSSM Neutral Higgs -> 3 b
  - Exploits the enhanced coupling to b-quarks present in the MSSM model
  - Suffers from large multi-jet backgrounds from QCD

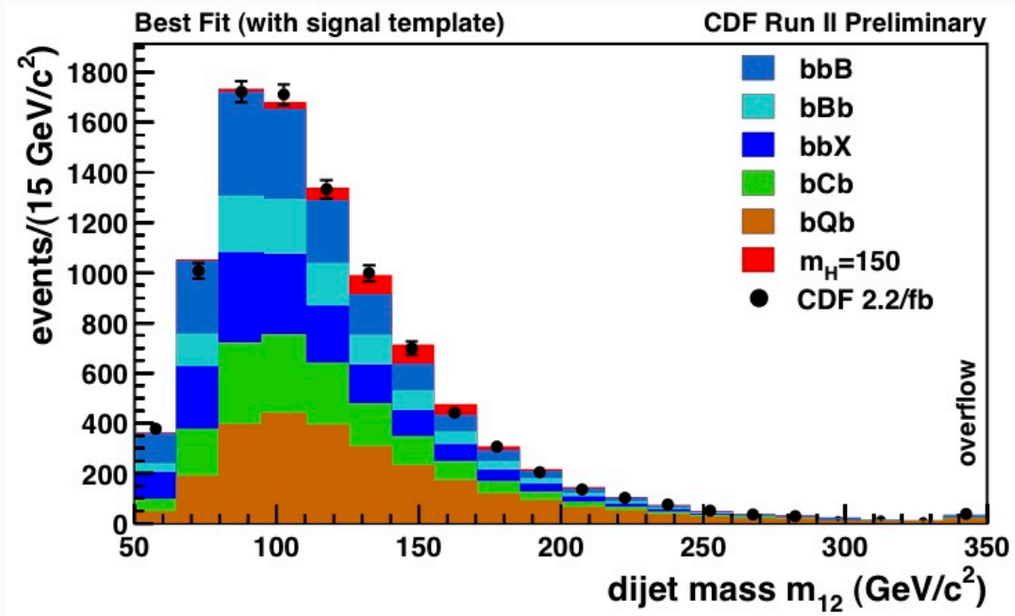


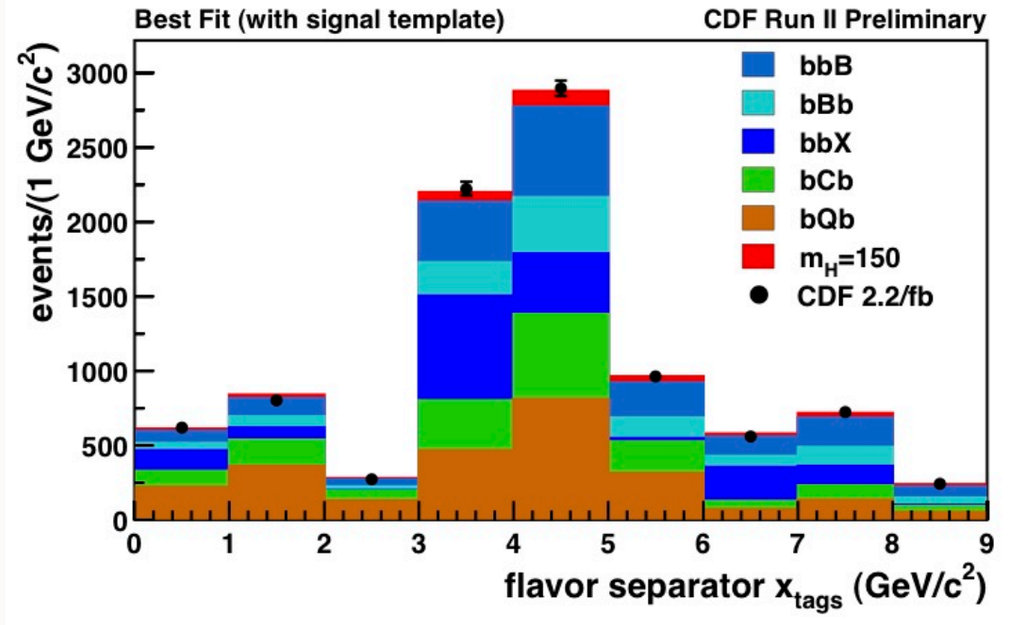


MSSM HIGGS -> 3 B JETS

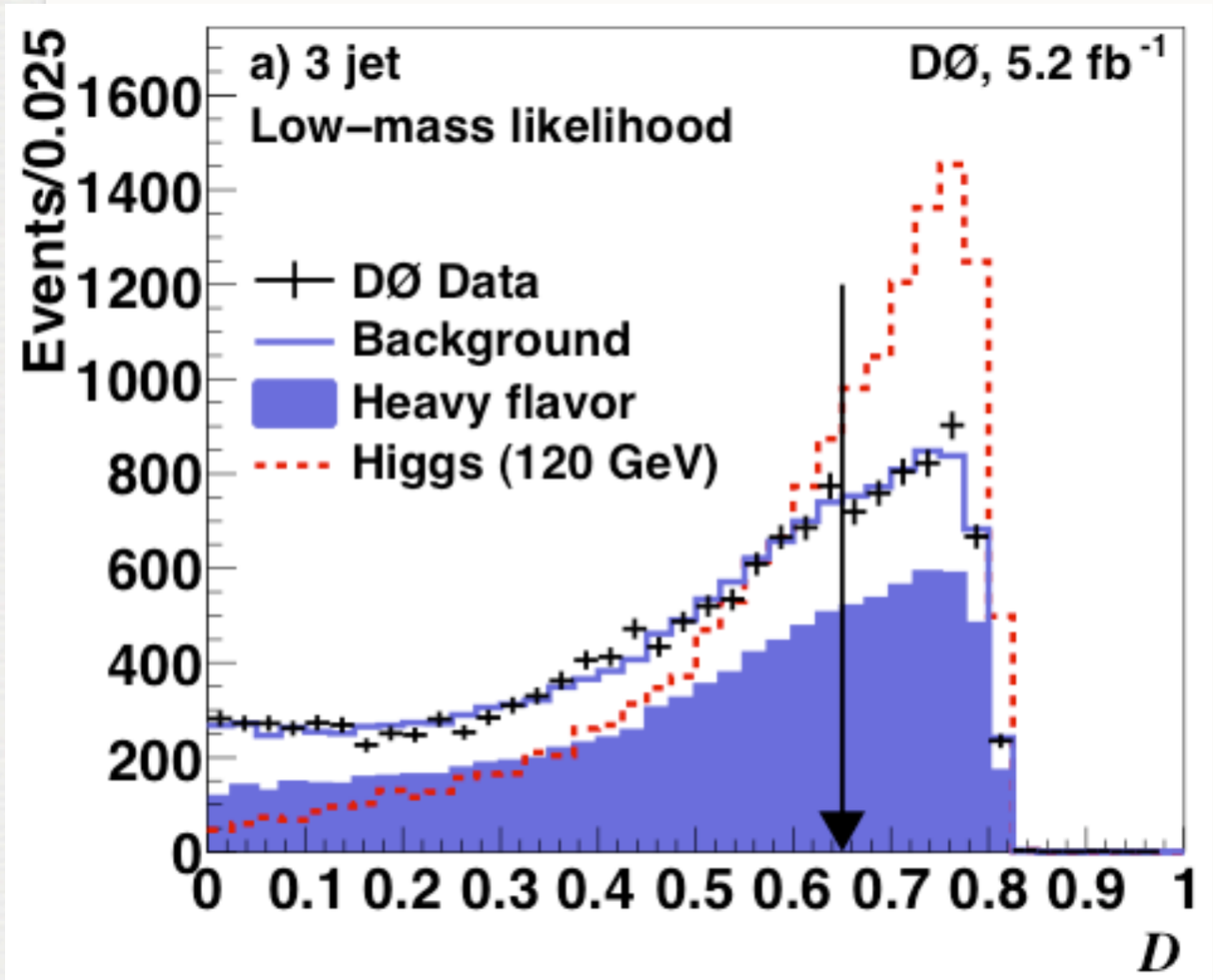
- Search for neutral Higgs decaying to $b\bar{b}$, produced in association with a b
- Requires 3 central high-et jets with b-tags
- Background is essentially QCD heavy-flavor multi-jet production, background model based off two tag sample







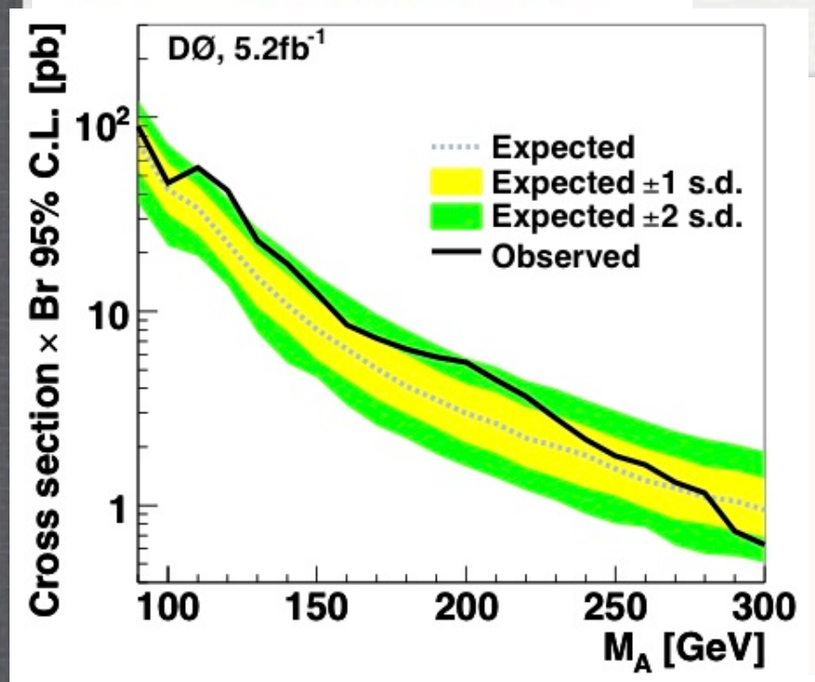
MSSM HIGGS -> B JETS

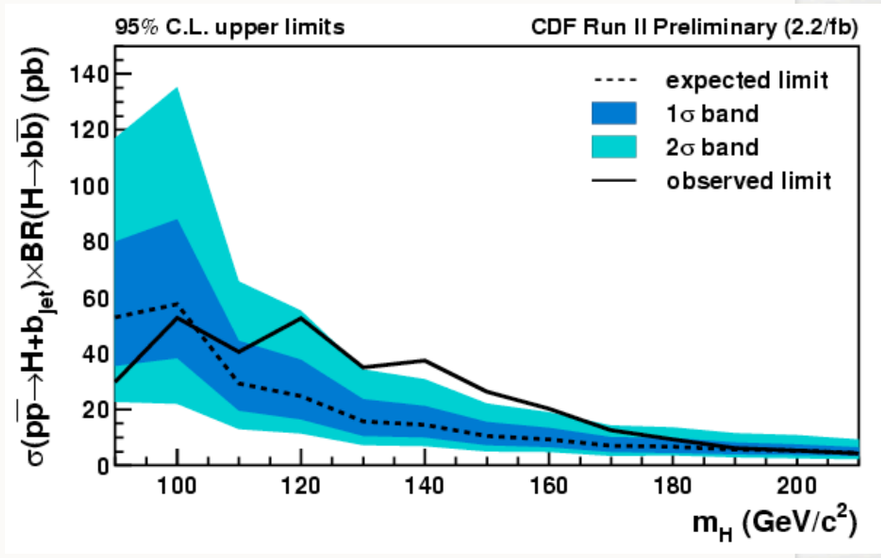


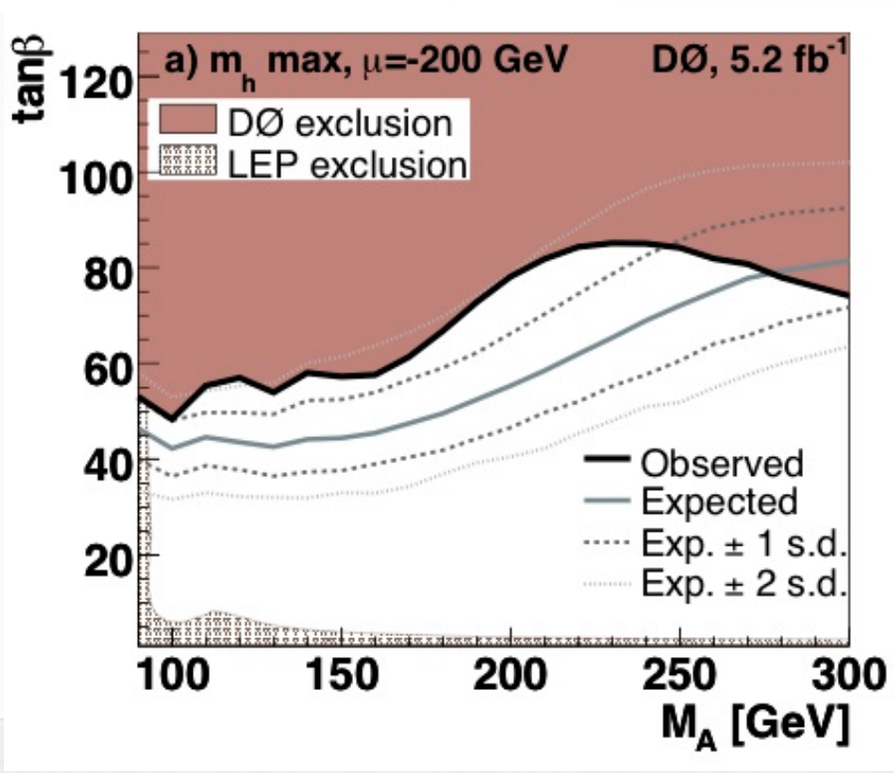
- Selects for 3 or 4 central high pt jets, with at least 3 b-tags from a neural net based tagger
- Data driven backgrounds from two tag samples with SF from MC
- Construct likelihood discriminant from several kinematic variables

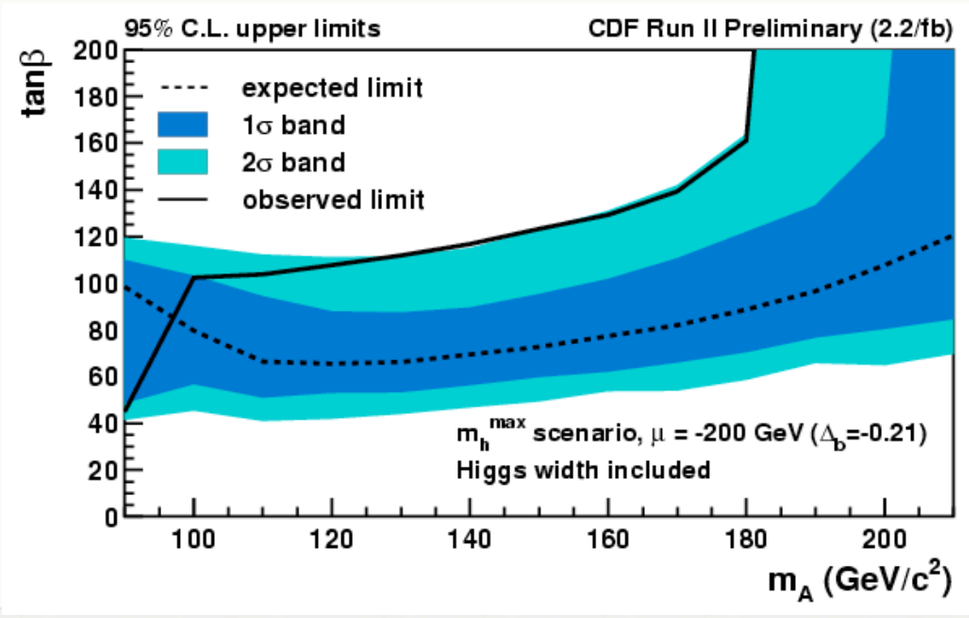
MSSM HIGGS -> B JETS

- Limits for zero-width model are then corrected for Higgs width and MSSM tan β corrections in MSSM scenario

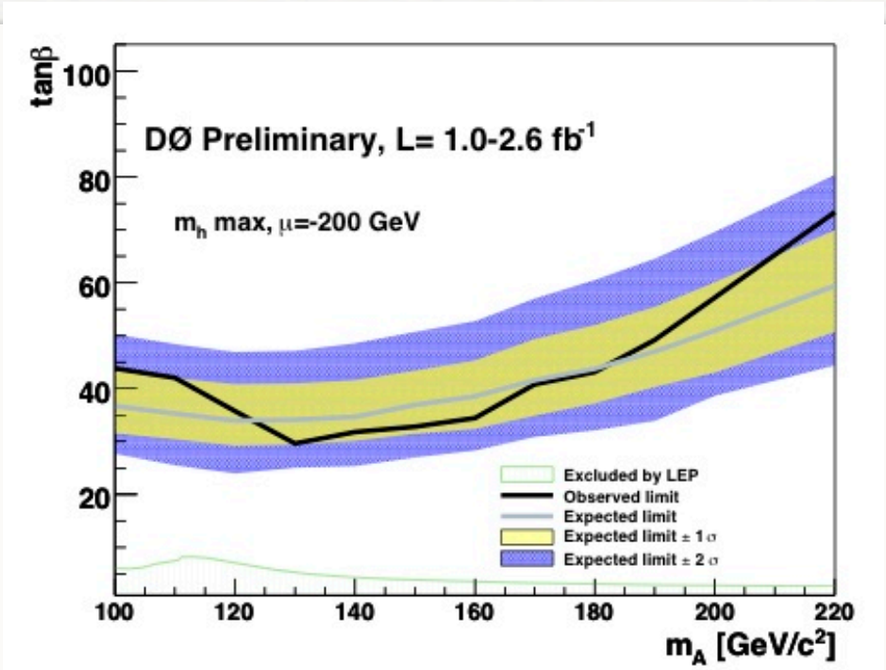


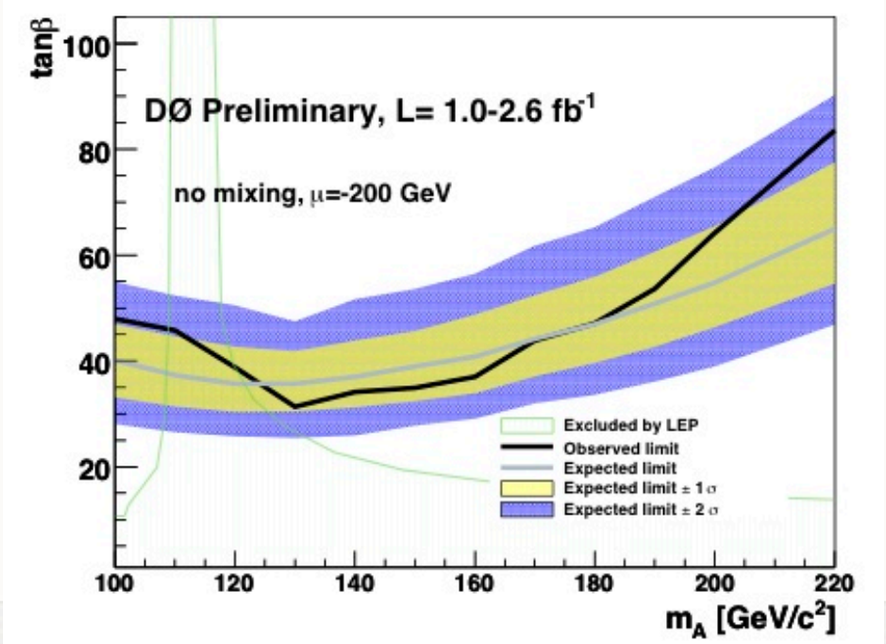






MSSM HIGGS COMBINATION

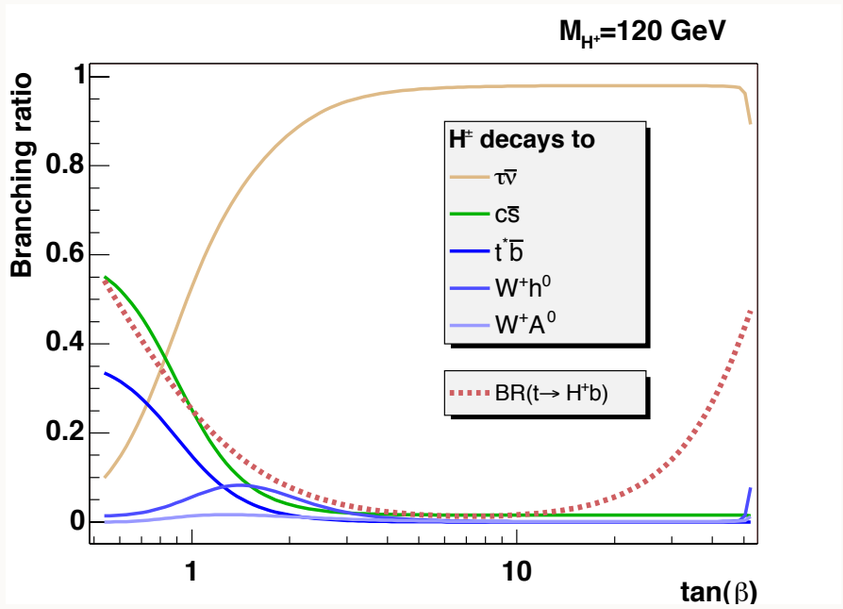


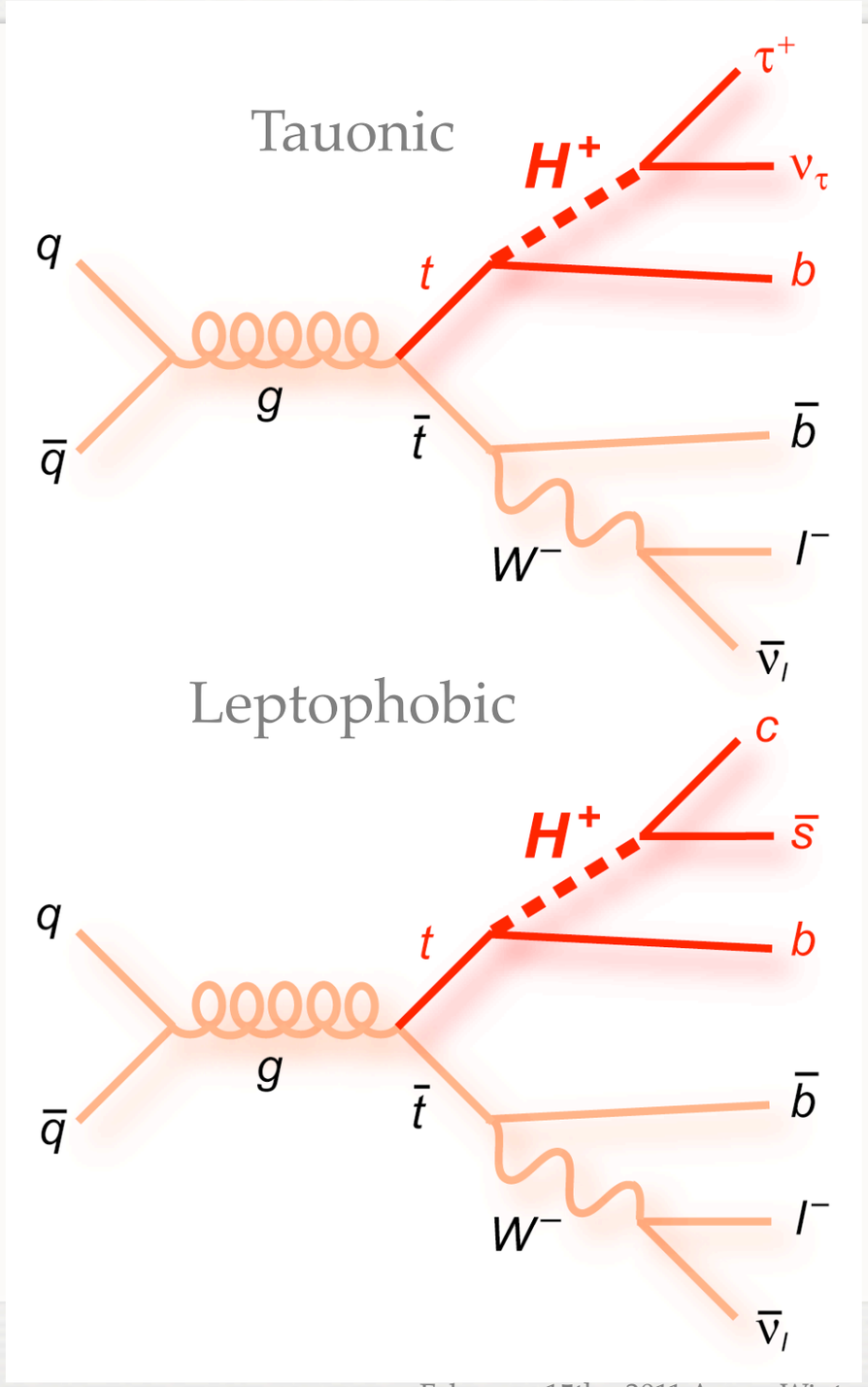


- Combines three d0 analysis
  - Higgs->ditau, Higgs+b->ditau +b (new) and Higgs+b->3b
- Uses modified frequentist approach to set limits for benchmark MSSM scenarios

MSSM CHARGED HIGGS

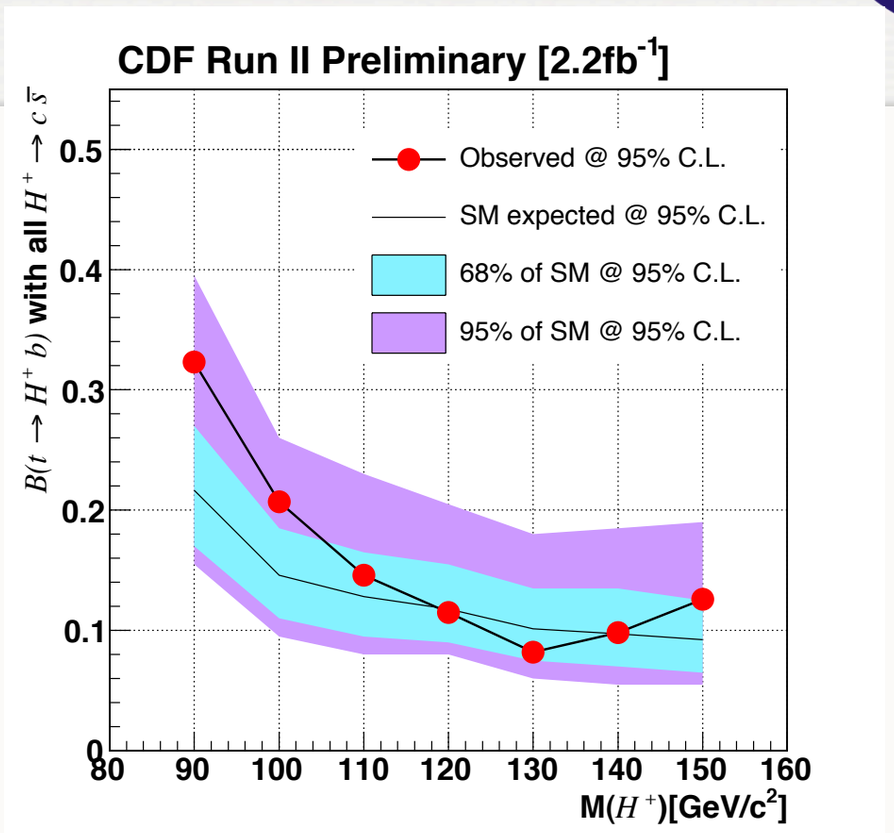
- MSSM Charged Higgs ($H^{\pm}$)
  - Charged Higgs
    - Appears in $t\bar{t}$ decay in place of $W^{\pm}$
    - Primarily sensitive to MSSM for low tan β, leptophobic and high tan β, tauonic and low m_A

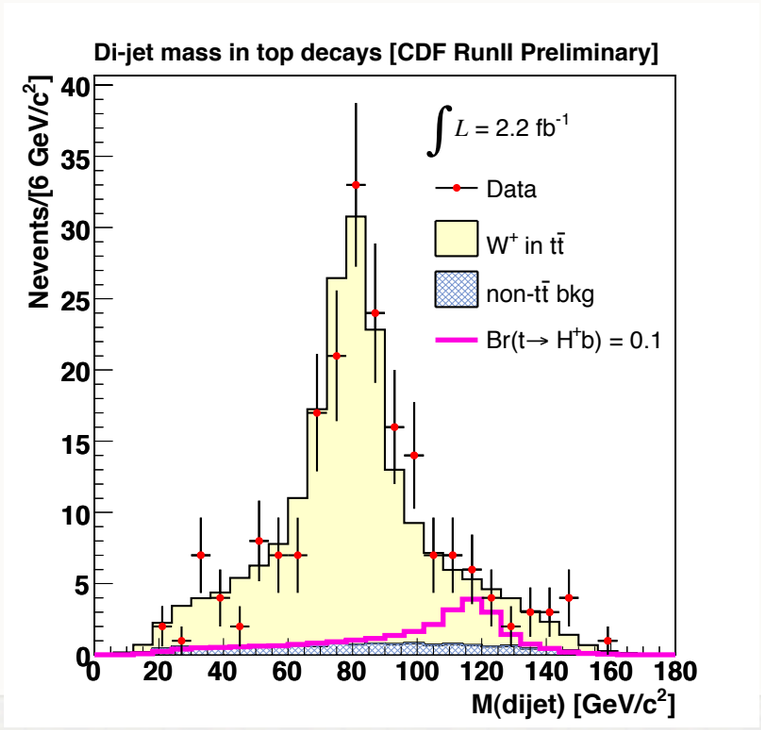




CHARGED HIGGS

- Search for $H^+ \to c\bar{s}$ in top decays, viable in MSSM for low tan β
- Select for one high pt lepton, large $\not\!\!E_T$, 4 or more central jets with at least 2 b-tags

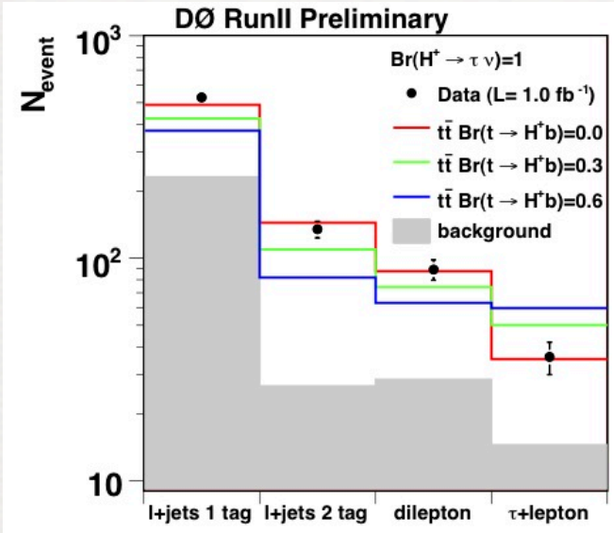




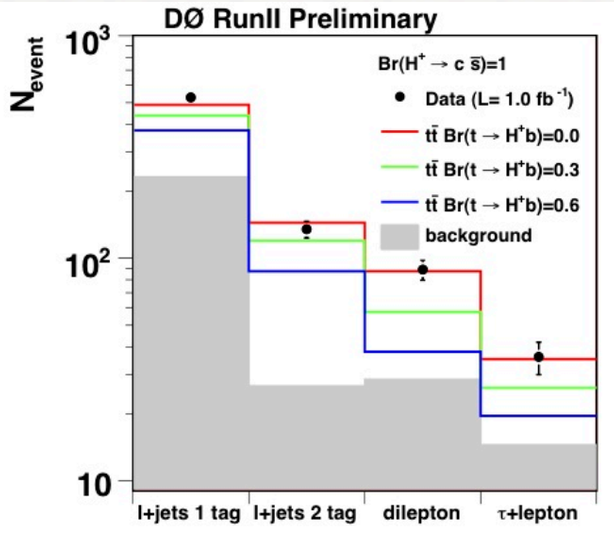
- Backgrounds from top, diboson, Z + jets, W + jets from MC. QCD backgrounds from data
- Binned likelihood fit used to extract signal limits

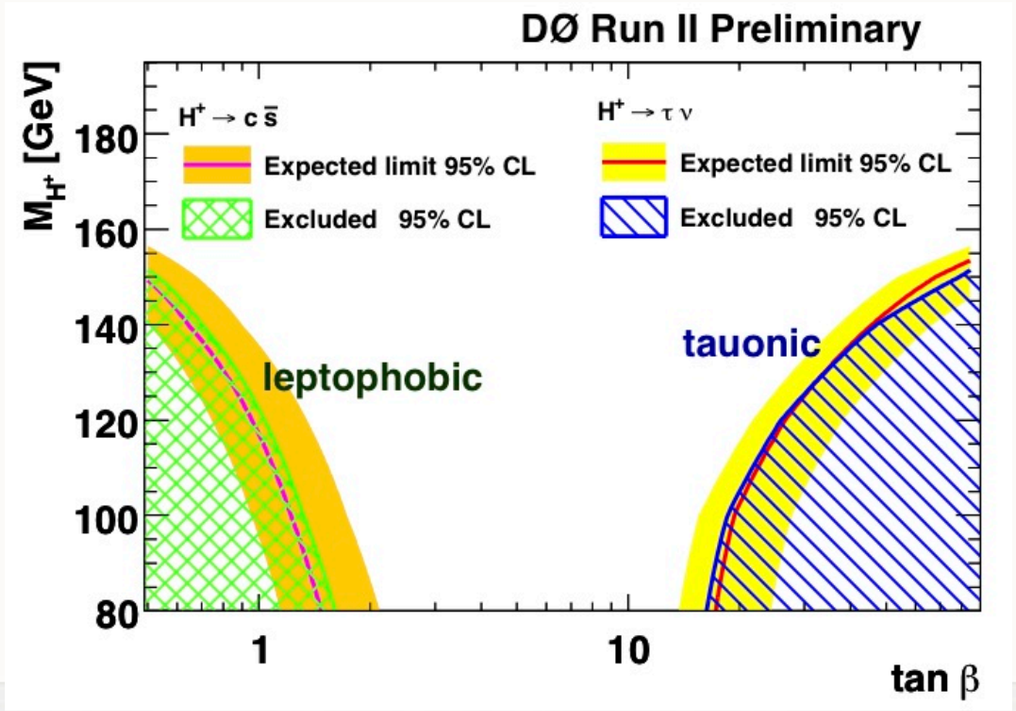
CHARGED HIGGS

Tauonic



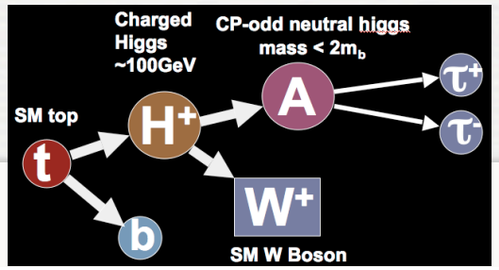
Leptophobic



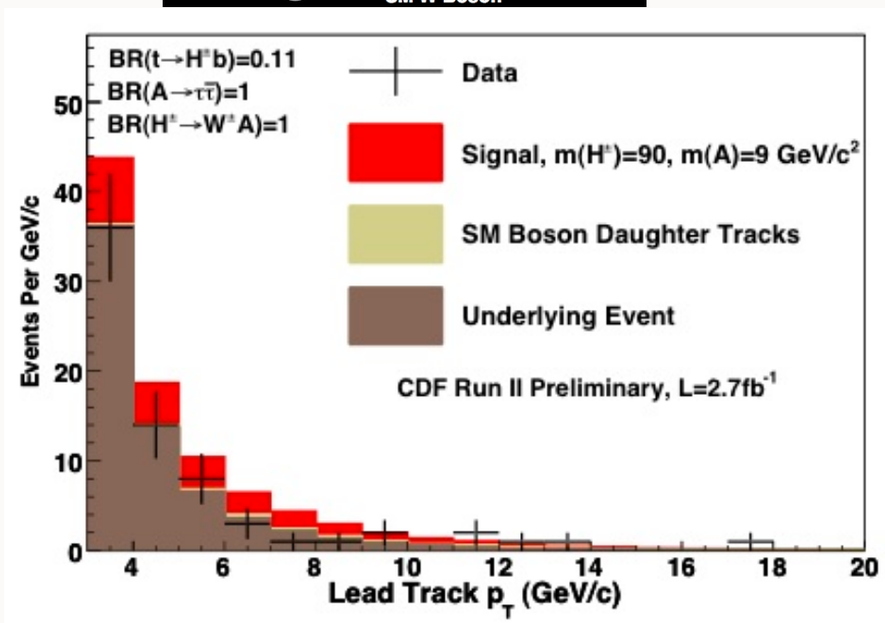


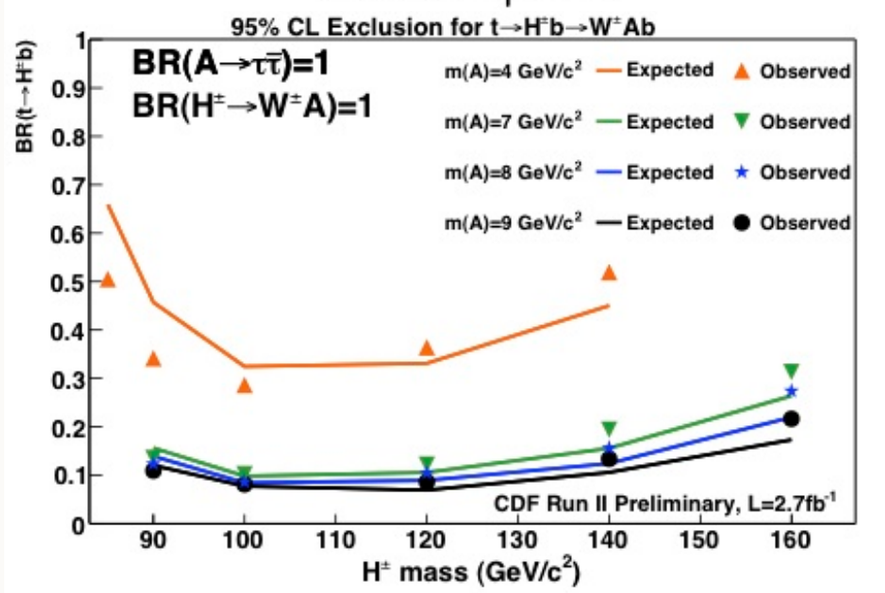
- Considers two models
  - tauonic model ($H^+ \rightarrow \tau\nu$)
  - leptophobic model ($H^+ \rightarrow c\bar{s}$)
- Uses three orthogonal channels
  - lepton+jets requires >=3 central high-pt jets, one isolated central electron or muon and large met
  - lepton + tau and dileptons, one or two isolated high-pt central leptons, taus use neural network identifier, lepton+tau requires a b-jet
- Maximum likelihood fit similar to techniques of $t\bar{t}$ cross section used to set limits

NMSSM CHARGED HIGGS

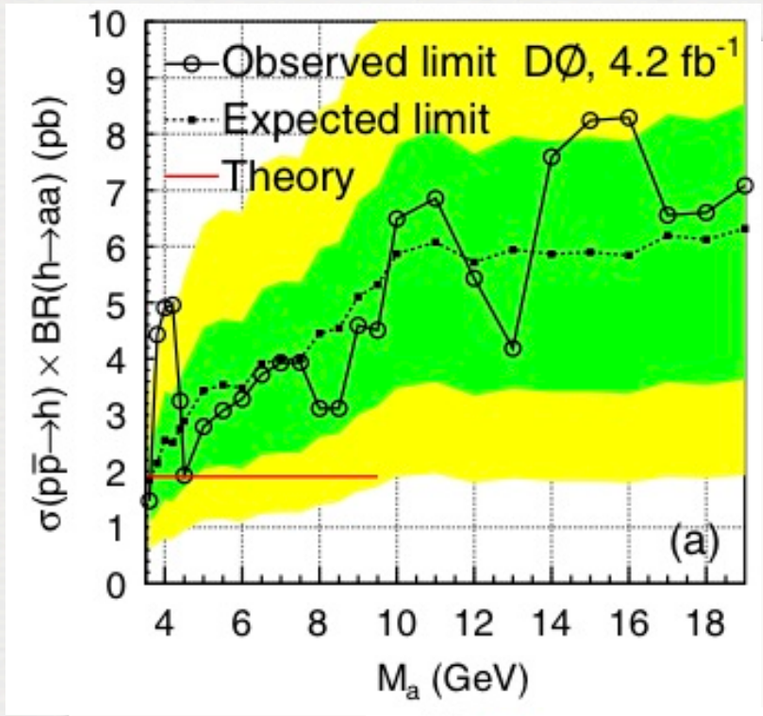


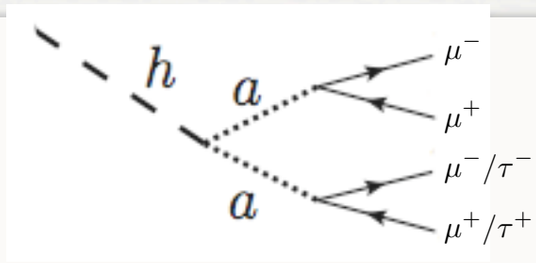
- Next-to-minimal supersymmetric standard model (NMSSM) search, for charged higgs in top decays
- NMSSM contains two additional neutral Higgs and one additional neutralino, avoids some LEP limits
- Require exactly one lepton, three or more jets with at least one b-tag
- Backgrounds from $t\bar{t}$ and W/Z+jets taken from MC
- Use presence of taus identified by low-pt isolated tracks to distinguish from standard top decays, otherwise apply $t\bar{t}$ event requirements



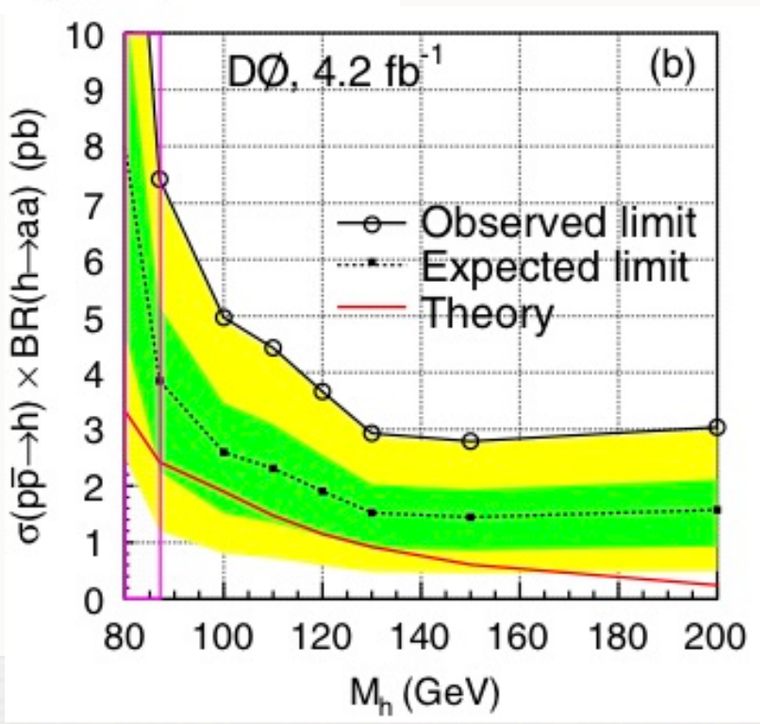


NMSSM NEUTRAL HIGGS



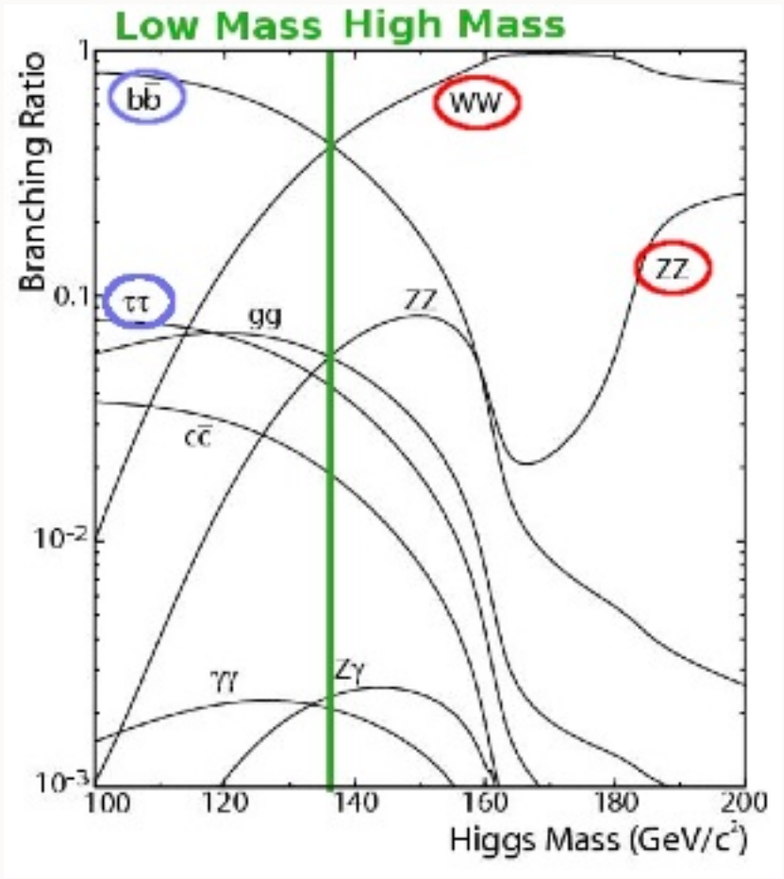


- Search for NMSSM neutral higgs decaying to $\mu\mu\mu\mu$ or $\mu\mu\tau\tau$
- Select for two pairs of collinear muons or one pair of collinear muons, large $\not\!\!E_T$, and a muon or loosely isolated electron
- Primary backgrounds are multi-jet events and Z+jets



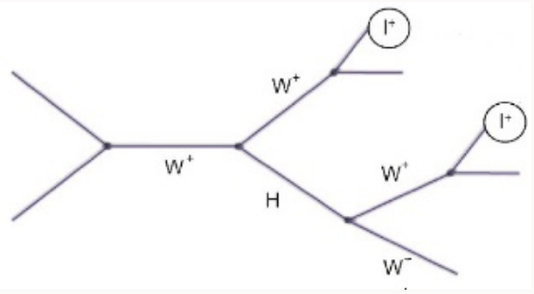
FERMIOPHOBIC HIGGS

- Fermiophobic Higgs
  - Assumes no Higgs coupling to fermions
  - Enhanced branching ratio to photons
  - Same coupling to W and Z bosons as SM

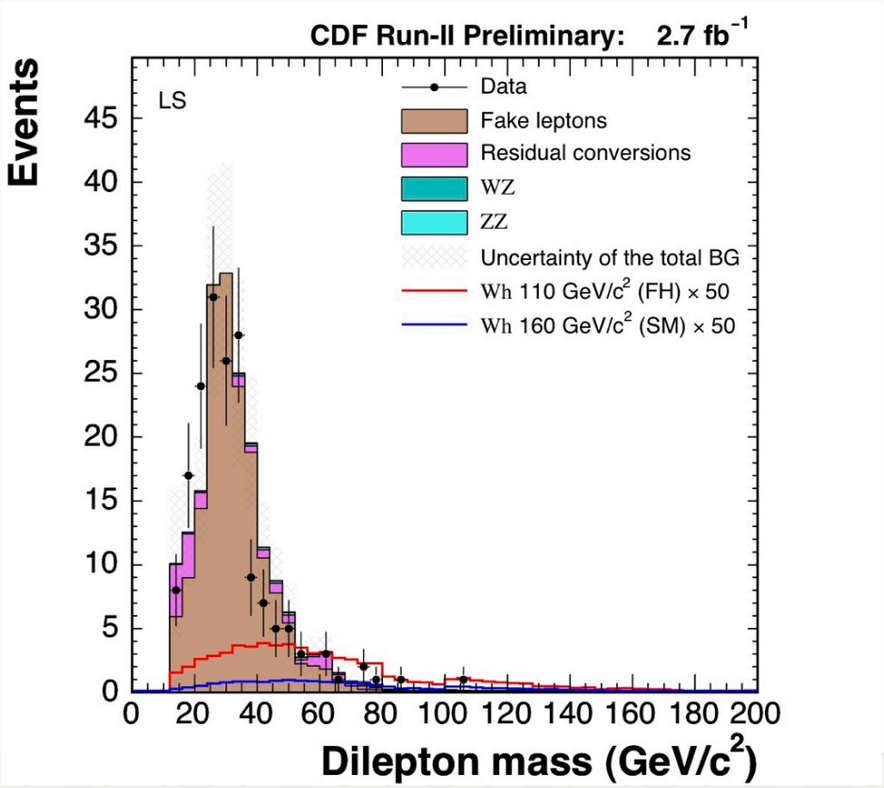


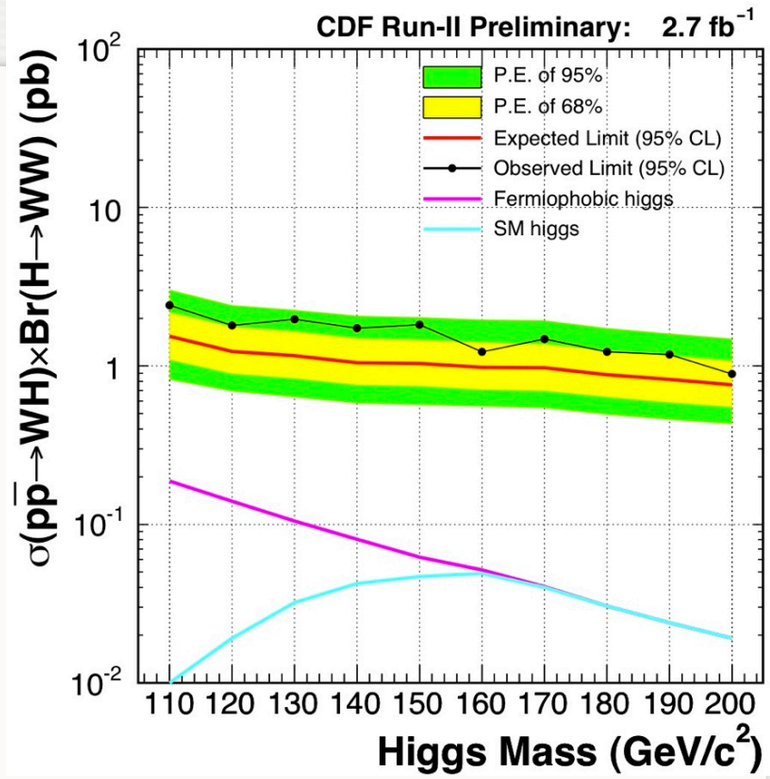
FERMIOPHOBIC - SS DILEPTON

- Search for neutral Higgs produced in association with a W using high-pt same sign leptons



- Backgrounds from dibosons, conversions and fake leptons



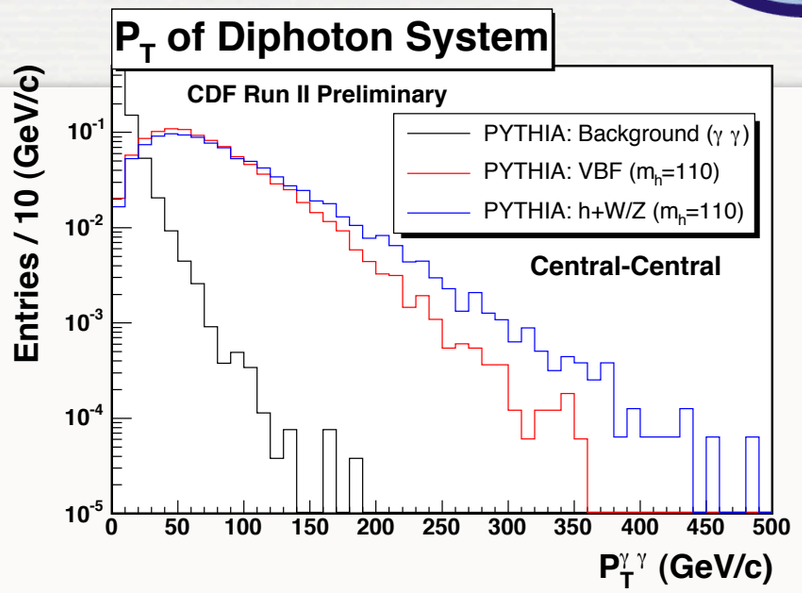


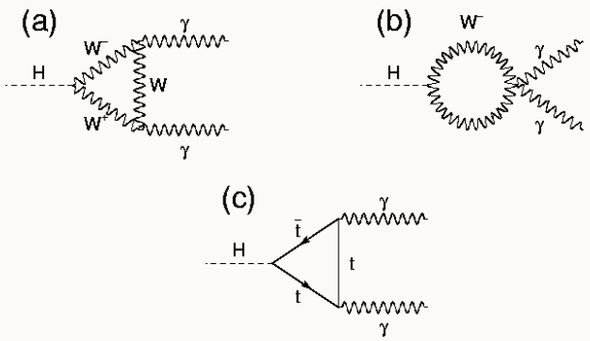
- Fermiophobic Higgs sensitivity at low mass

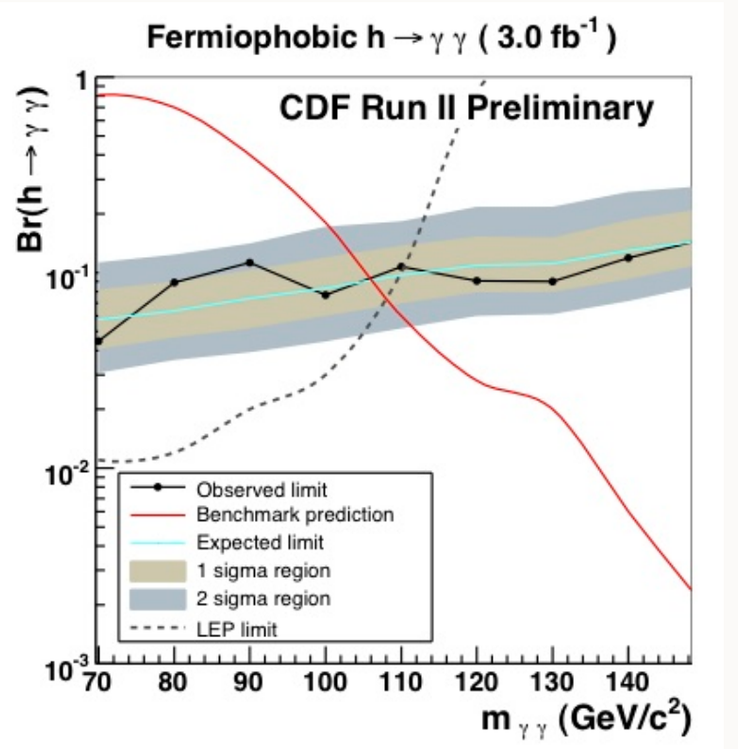
- Uses a boosted decision tree to separate signal and background, followed by a bayesian approach to limits

FERMIOPHOBIC - DIPHOTON

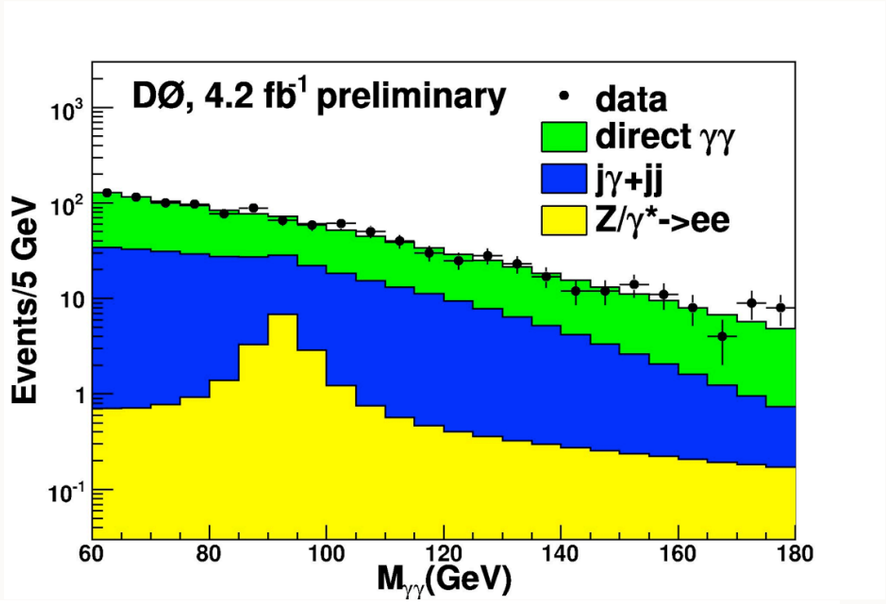
- Low diphoton SM branching ratio (~0.2%) enhanced in fermiophobic models for low mass Higgs
- Diphoton signature is a very narrow peak
- High di-photon pt cut used (> 75 GeV/c^2) due to hard spectrum
- Background shape extracted from sidebands

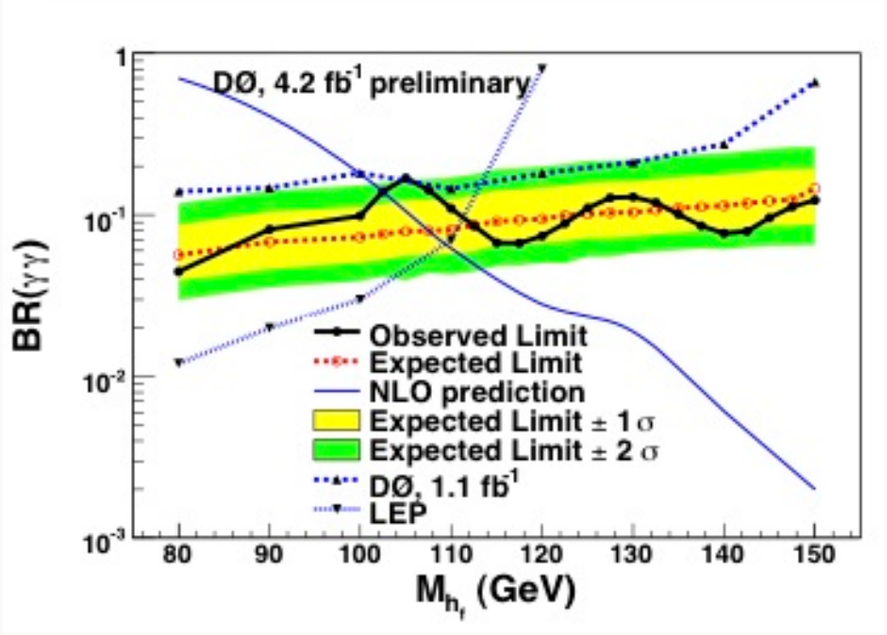






FERMIOPHOBIC - DIPHOTON





- Event selection requires two central photons and a $p^T_{\gamma\gamma} > 35$ GeV
- Backgrounds
  - Drell-Yan (MC)
  - gamma+jet and di-jet (data)
  - di-photon (sideband)

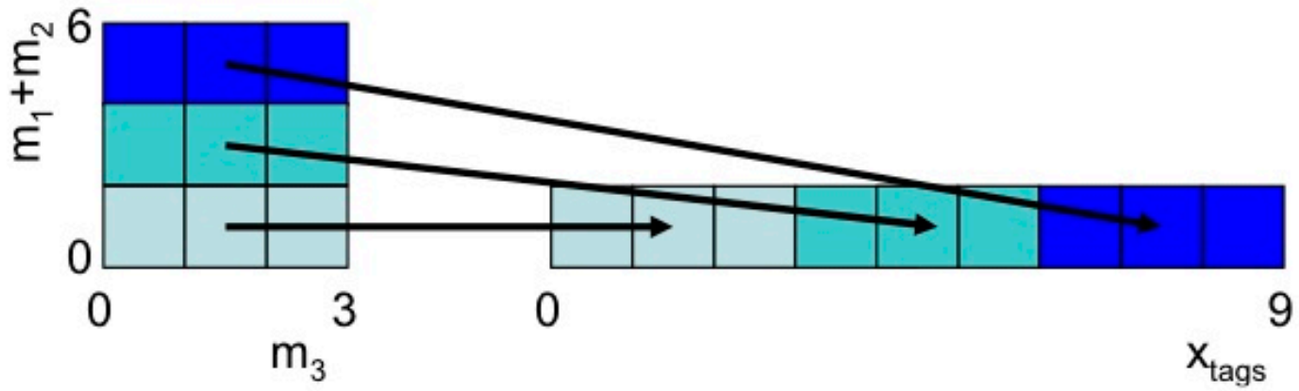
CONCLUSIONS

- Active and widespread program of BSM Higgs searches
- Updates underway in many channels
- Lots of data still to be utilized, the Tevatron has more to say about BSM Higgs
- For more see
  - http://www-cdf.fnal.gov/physics/new/hdg/hdg.html
  - http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm

BACKUP

3-B CHANNEL

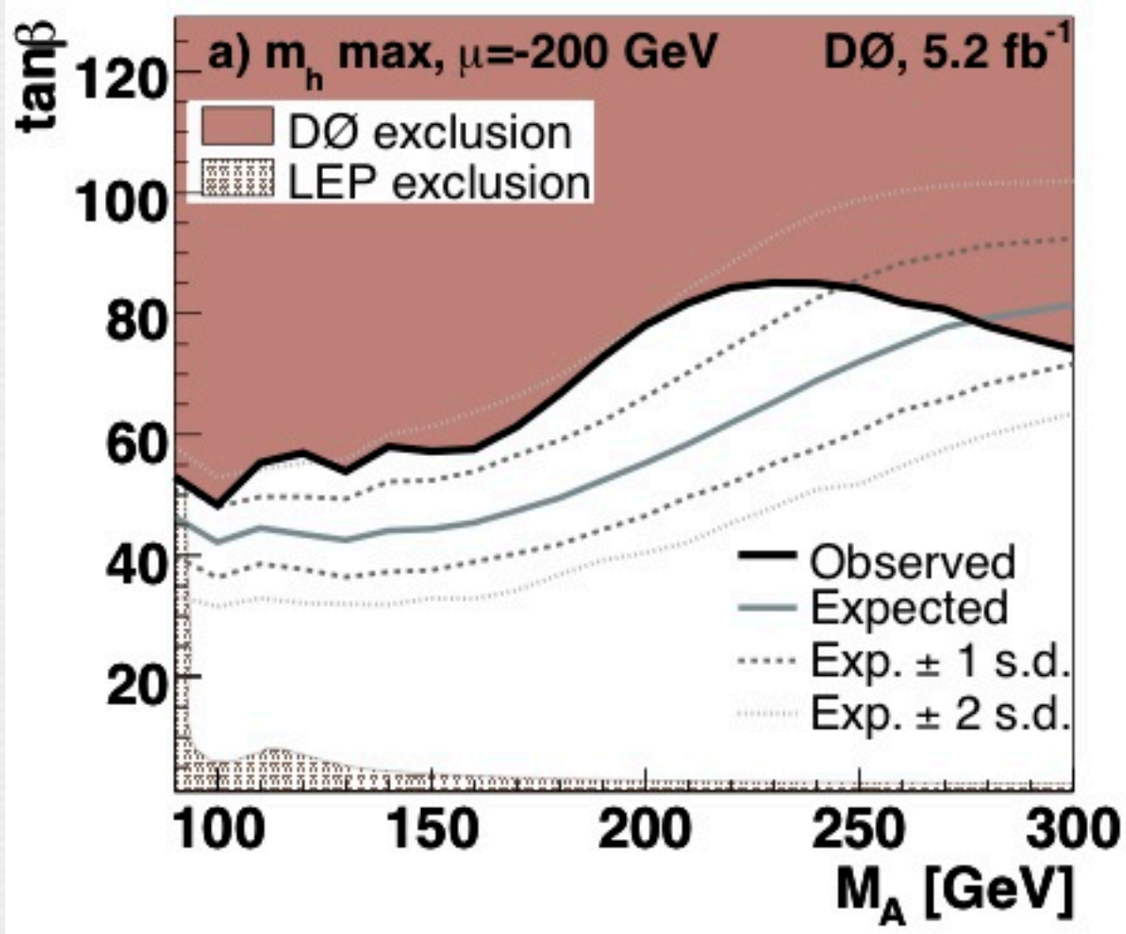
FIG. 4: Illustration of the x_{tags} definition.

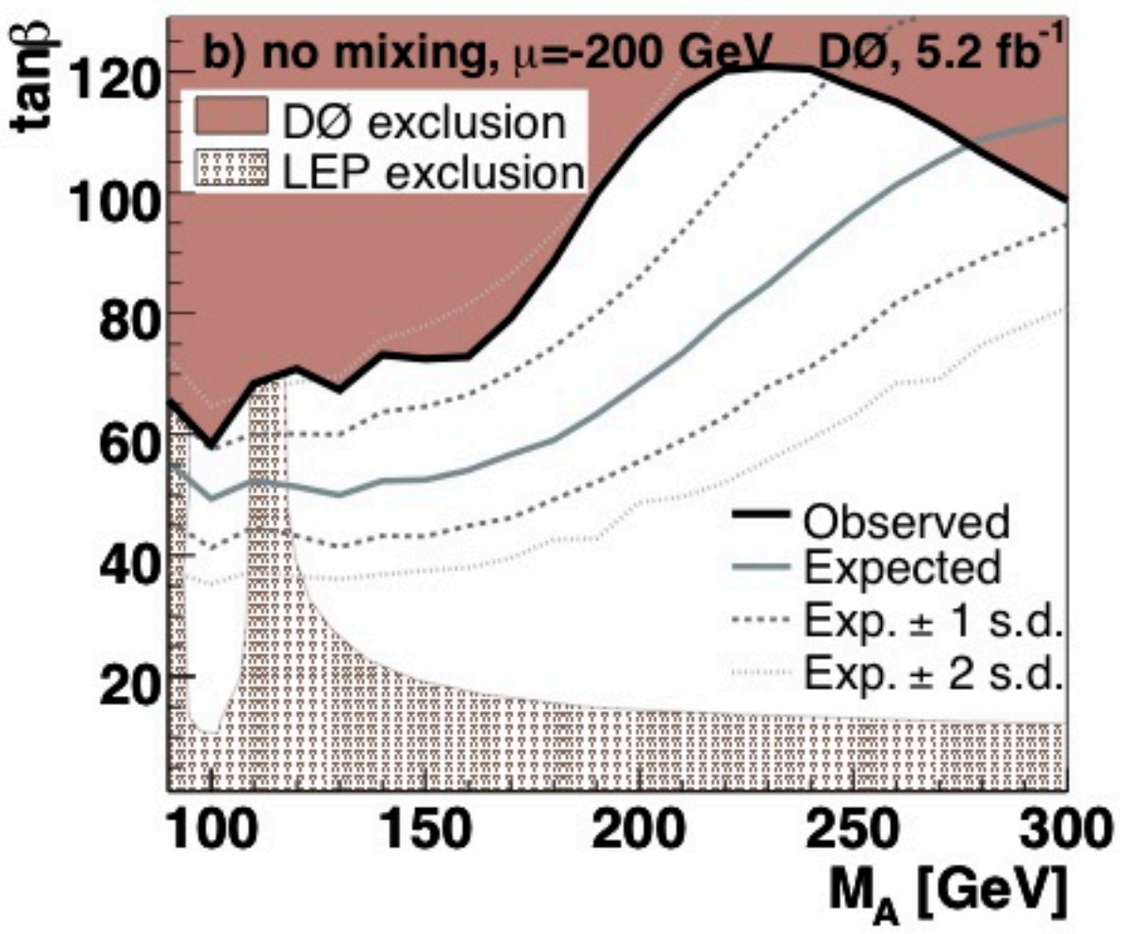


The x_{tags} variable is defined as

$$x_{tags} = \begin{cases} \max(m_3^{tag}, 2.99) & : \quad m_1^{tag} + m_2^{tag} < 2 \\ \max(m_3^{tag}, 2.99) + 3 & : \quad 2 \leq m_1^{tag} + m_2^{tag} < 4 \\ \max(m_3^{tag}, 2.99) + 6 & : \quad m_1^{tag} + m_2^{tag} \geq 4 \end{cases} \tag{1}$$

where $\max(a, b)$ returns the maximum of a and b, and all quantities are in units of GeV/c^2. The net effect is to unstack a two-dimensional histogram of $m_1^{tag} + m_2^{tag}$ versus m_3^{tag} into the one-dimensional variable x_{tags}, as illustrated in Figure 4.


a) m_h max, μ=-200 GeV
DØ, 5.2 fb^-1
DØ exclusion
LEP exclusion
Observed
Expected
Exp. ± 1 s.d.
Exp. ± 2 s.d.
tanβ
M_A [GeV]


b) no mixing, μ=-200 GeV
DØ, 5.2 fb^-1
DØ exclusion
LEP exclusion
Observed
Expected
Exp. ± 1 s.d.
Exp. ± 2 s.d.
tanβ
M_A [GeV]

D0 - 3b search

M_A [GeV]	Observed [pb]	Expected [pb]
90	89.5	73.9
100	46.0	42.5
110	55.0	34.0
120	42.0	22.6
130	23.1	15.0
140	17.6	10.8
150	12.4	8.05
160	8.52	6.38
170	7.24	5.05
180	6.37	4.11
190	5.82	3.51
200	5.46	2.98
210	4.43	2.64
220	3.65	2.23
230	2.80	2.02
240	2.19	1.81
250	1.80	1.55
260	1.62	1.35
270	1.31	1.23
280	1.16	1.10
290	0.73	1.06
300	0.63	0.95

TABLE II: Model independent 95% C.L. upper limits on the cross section times branching ratio for the combined 5.2 fb^{-1} analysis.

CDF - 3b search

TABLE IV: Median expected and observed limits on $\sigma(p\bar{p} \to bH) \times BR(H \to b\bar{b})$, in pb.

m_H	no systematics	full systematics	observed
90	41.3	53.0	29.8
100	40.8	57.7	52.7
110	22.8	29.3	40.5
120	20.3	24.7	52.5
130	12.9	15.7	35.0
140	11.9	14.5	37.5
150	8.6	10.5	26.4
160	7.9	9.2	20.3
170	6.0	7.0	12.6
180	5.6	6.7	9.3
190	4.8	5.7	6.1
200	4.5	5.3	5.3
210	3.9	4.5	4.3